QUARTERLY REPORT

(for July 1 - September 30, 1998)

Contract No. NAS5-31363

OCEAN OBSERVATIONS WITH EOS/MODIS
Algorithm Development and Post Launch Studies

by

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Preamble

This report is briefer than usual because it was prepared quickly, as we expected the contract would be amended to remove the requirement for quarterly reports.

Report

I shall describe developments (if any) in each of the major task categories.

1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1998 there are seven objectives under this task. Objectives (i) and (ii) below are considered to be the most critical. If the work planned under objective (i) is successful, a module that enables the algorithm to distinguish between weakly- and strongly-absorbing aerosols will be included in the atmospheric correction algorithm.

(i) We will continue the study of the "spectral matching" algorithm. The initial realization of the algorithm will be to provide a flag that will signal the probable presence of absorbing aerosols, and indicate that the quality of the derived products cannot be assured. Later realizations will provide an atmospheric correction in the presence of absorbing aerosols. In addition, we need to develop adequate models of absorbing aerosols, in particular desert dust.

(ii) We need to test the basic implementation of the MODIS atmospheric correction algorithm with actual ocean color imagery. We will do this with SeaWiFS imagery.

(iii) We must implement our strategy for adding the cirrus cloud correction into the existing atmospheric correction algorithm. Specific issues include (1) the phase function to be used for the cirrus clouds, (2) the details of making two passes through the correction algorithm, and (3) preparation of the required tables. These issues will be addressed as time permits in CY 1998.

(iv) The basic correction algorithm yields the product of the diffuse transmittance and the water-leaving reflectance. However, we have shown that the transmittance depends on the angular distribution of the reflectance only when the pigment concentration is very low and then only in the blue. We need to develop a model to include the effects of the subsurface BRDF for low-pigment waters in the blue.

(v) We need to study the efficacy of the present atmospheric correction algorithm for removal of the aerosol effect from the measurement of the fluorescence line height.

(vi) We need to examine methods for efficiently including earth-curvature effects into the atmospheric correction algorithm. This will most likely be a modification of the look-up tables for the top-of-the-atmosphere contribution from Rayleigh scattering.

(vii) We will examine the necessity of implementing out-of-band corrections to MODIS.

b. Task Progress:

(i) We consider this task to be one of our most important atmospheric correction activities of 1998 [the other is item (ii) above: testing MODIS algorithms with SeaWiFS imagery], and as such, the major part of our effort on atmospheric correction will be focussed on it. We have implemented the spectral matching algorithm described by Chomko and Gordon [R. Chomko and H.R. Gordon, Atmospheric correction of ocean color imagery: Use of the Junge power-law aerosol size distribution with variable refractive index to handle aerosol absorption, Applied Optics, 37, 5560-5572 (1998)], in which power-law size distributions are utilized, in the SEADAS image processing environment. The power-law distribution allows a straightforward interpolation to size distributions that are not part of the candidate set. We also interpolate on the real and imaginary parts of the complex refractive index. Thus, a complete spectrum of models can be generated from a relatively small candidate set. We then use standard optimization techniques to find the best fitting set of parameters. Thus far, two images have been processed, and the results are being evaluated in comparison with the standard SeaWiFS/MODIS algorithm.

We also started a major effort to understand the optical properties of desert dust transported over the oceans. This is being carried out in conjunction with R. Evans. Cyril Moulin has started as a postdoc on the project and is working nearly full time on this problem. The idea is to use SeaWiFS imagery from the Tropical Atlantic acquired this summer, along with the results from the Virgin Islands field experiment (see 5.b.ii), to delineate the dust properties.

(ii) We are acquiring SeaWiFS imagery on a regular basis and, with R. Evans, are evaluating the performance of the SeaWiFS/MODIS atmospheric correction algorithm.

(iii) No work was carried out on this task.

(iv) We continued the development of an oceanic BRDF model. Specifically, the magnitude of the Raman component has been computed as a function of the pigment concentration.

(v) No work was carried out on this task.

(vi) No work was carried out on this task.

(vii) We are in the process of computing the various spectral averages required for applying the procedures described by Gordon (1995) ["Remote sensing of ocean color: a methodology for dealing with broad spectral bands and significant out-of-band response", Applied Optics, 34 8363-8374 (1995)].

c. Anticipated Activities During the Next Quarter:

(i) We will continue preparations to test the new spectral matching algorithm using SeaWiFS imagery. We will continue our dust study.

(ii) With R. Evans, we will complete the MODIS atmospheric correction algorithm using SeaWifs imagery. The goal is to validate the algorithm.

(iii) None.

(iv) We will continue the modeling of the BRDF.

(v) None.

(vi) None.

(vii) We will provide tables of the spectral averages in the next semi-annual report.

d. Publications:

R. Chomko and H.R. Gordon, Atmospheric correction of ocean color imagery: Use of the Junge power-law aerosol size distribution with variable refractive index to handle aerosol absorption, Applied Optics, 37, 5560-5572 (1998).

2. Whitecap Correction Algorithm (with K.J. Voss)

As the basic objectives of the experimental portion of this task has been realized (acquiring whitecap radiometric data at sea), experimental work is being suspended until the validation phase, except insofar as the radiometer will be operated at sea when sufficient number of personnel are available. Our goal is to maintain experience in operating and maintaining the instrumentation in preparation for the validation phase of the contract. In addition, we need to reanalyze the Tropical Pacific whitecap data to better bound the limits of oceanic whitecap reflectance.

a. Near-term Objectives:

Reanalyze data acquired during the Tropical Pacific cruise.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter:

We will begin the reanalysis of the Tropical Pacific data with the goal of submitting a revised manuscript on whitecap reflectance by the end of the calendar year or early 1999.

d. Publications: None.

3. In-water Radiance Distribution (with K.J.Voss)

The main objective in this task is to obtain upwelling radiance distribution data at sea for a variety of solar zenith angles to understand how the water-leaving radiance varies with viewing angle and sun angle. This is the experimental component of our BRDF modeling.

a. Near-term Objectives: None

b. Task Progress: None

c. Anticipated Activities During the Next Quarter:

We will continue to evaluate and work with the data acquired thus far, however, the main focus will be to get the instrumentation ready for our participation in INDOEX.

d. Publications: None.

4. Residual Instrument Polarization.

The basic question was, if the MODIS responds to the state of polarization state of the incident radiance, given the polarization-sensitivity characteristics of the sensor, how much will this degrade the performance of the algorithm for atmospheric correction? We developed a formalism which provides the framework for removal of instrumental polarization-sensitivity effects, and an algorithm for removing much of the error induced by the polarization sensitivity.

a. Near-term Objectives: None.

b. Task Progress: None

c. Anticipated Activities During the Next Quarter:

Incorporate SBRS/MCST polarization-characterization data (if available) into our module for correcting for the MODIS residual instrument polarization.

d. Publications: None

5. Pre and Post-launch Atmospheric Correction Validation and Vicarious Calibration/Initialization (with K.J. Voss)

a. Task Objectives:

The objectives of this task are four-fold:

(i) First, we need to study aerosol optical properties over the oceans to assess the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this required obtaining long-term time series of the aerosol optical properties in typical maritime environments. This is being achieved using a CIMEL sun/sky radiometer. This radiometer is identical to those used in the AERONET Network (of which we are a participant).

(ii) Second, we must be able to measure the aerosol optical properties from a ship during the initialization/calibration/validation cruises. The CIMEL-type instrumentation could not be used (due to the motion of the ship) for this purpose. The required instrumentation consisted of an all-sky camera (which can measure the entire sky radiance, with the exception of the solar aureole region) from a moving ship, an aureole camera (specifically designed for ship use) and a hand-held sun photometer.

In the case of strongly-absorbing aerosols, we have shown that knowledge of the aerosol vertical structure is critical. Thus, we need to be able to measure the vertical distribution of aerosols during validation exercises as well as to build a climatology of the vertical distribution of absorbing aerosols. This is accomplished with a LIDAR system, which we have modified for ship operations.

(iii) The third objective was to determine how accurately the radiance at the top of the atmosphere can be determined based on measurements of sky radiance and aerosol optical thickness at the sea surface. This required a critical examination of the effect of radiative transfer on "vicarious" calibration exercises.

(iv) The forth objective is to utilize data from other sensors that have achieved orbit (OCTS, POLDER, SeaWiFS ...) to validate and fine-tune the correction algorithm.

b. Task Progress:

(i) We have been operating the CIMEL instrument in the Dry Tortugas continuously during most of the quarter. It has worked well (even through Hurricane Georges).

(ii) We acquired sky radiance and aureole data with the instruments during the MOCE-4. We are continuing the analysis of this data.

We deployed the LIDAR in the Virgin Islands from mid July to mid August to study the properties of Saharan dust. A significant amount of data was acquired in both dust and dust-free times simultaneously (or contemporaneously) with SeaWiFS overpasses. CIMEL data was also obtained during a portion of the experiment.

(iii) The theoretical aspects of this work have been completed. The next phase is to use surface measurements to predict top-of-atmosphere radiance.

(iv) Our work under this objective is described under Section 1-ii.

c. Anticipated Activities During the Next Quarter:

(i) We will continue to keep the CIMEL operating in the Dry Tortugas, including the monthly maintenance checks.

(ii) We will be focusing on reducing the data from the Virgin Islands, as well as continuing work on the MOCE-4 data. We are having the LIDAR unit repaired (it failed after the Virgin Islands experiment) and have ordered a spare power supply to ensure against similar failures in the winter-spring INDOEX experiment.

(iii) We attempt to use data acquired during MOCE-4 to effect the vicarious calibration SeaWiFS Band 8 (865 nm).

(iv) See Section 1.ii.

d. Publications: None.

6. Detached Coccolith Algorithm and Post Launch Studies.

a. Near-term Objectives:

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, E. huxleyi is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies focused on laboratory cultures to understand factors affecting the calcite-specific backscattering coefficient. A thorough understanding of the relationship between calcite abundance and light scattering, in situ, will provide the basis for a generic suspended calcite algorithm. As with algorithms for chlorophyll, and primary productivity, the natural variance between growth related parameters and optical properties needs to be understood before the accuracy of the algorithm can be determined. To this end, the objectives of our coccolith studies during this previous 3 months have been:

1) Working up data from our June '98 MODIS Gulf of Maine cruise.

2) Final pre-publication formatting of JGR manuscript on coccolith scattering properties.

3) Continued microscope cell/coccolith counts for latest samples from the Gulf of Maine.

4) Final publication of a paper on coccolith optical properties (with Ken Voss and Katherine Kilpatrick.

b. Task Progress:

Overview of MODIS work

For perspective on the directions of our work, we provide a brief overview of our previous activities. During 1995, we focussed on the optical properties of coccolithophores using chemostat cultures (in which algal growth rate was precisely controlled). During the latter half of 1995, our work focused on shipboard measurements of suspended calcite and estimates of optical backscattering as validation of the laboratory measurements. We participated on two month-long cruises to the Arabian Sea, measuring coccolithophore abundance, production, and optical properties. During 1996, we focused again on an examination of coccolith optics, during three Gulf of Maine cruises, one in March, one in June, and one in November. During 1997, we continued processing samples from our previous cruises, upgraded our laser light scattering photometer used in all of the calcite scattering measurements, performed two pre-launch cruises during which we estimated calcite particle optics in the Gulf of Maine, and analyzed our results from the MODIS-funded flow cytometer work. It should be noted that during the first cruise of 1997, we provided some of the only sea-truth numbers for the now defunct Japanese OCTS instrument.

Work performed this quarter

1) CHN filters (for analysis of total suspended carbon) from the November '97 cruise and June '98 cruise have been dried, in preparation for sending off for analysis (by Bermuda Biological). They will be shipped following the end of our cruise schedule aboard the M/S Scotian Prince in late October. We will process our backlog of suspended calcite samples at the same time, which is critical to future algorithm development activities.

2) Our flow cytometer manuscript submitted to J. Geophysical Research in the last quarter of 1997 has now been revised and accepted.

3) Continued microscope cell/ coccolith counts for samples from the Gulf of Maine. We have completed almost all counts June '98, and working on enumeration of September-October '98 samples.

4) Data sets for November '97 and June '98 have been submitted to the NASA SeaBass data archive.

5) We've completed analysis of our Arabian Sea coccolith distribution data. The first manuscript on these results is 3/4 complete and the second will be started after completion of the first.

6) Manuscript on Emiliania huxleyi (coccolithophore) optical properties was published by Limnology and Oceanography.

7) Five cruises across the Gulf of Maine to monitor coccolith optical properties. These data are still being worked up.

c. Anticipated Activities During the Next Quarter

1) Continue work on our Arabian Sea MODIS results on coccolith densities and associated optical properties.

2) Continued microscope cell/ coccolith counts for water samples from ten Gulf of Maine cruises aboard a ship of opportunity, the M/V Scotian Prince.

3) Suspended calcite samples from the Gulf of Maine November '97, June '98, and Sept-Oct '98 cruises will be run in the graphite furnace atomic absorption spectrometer at the University of Maine.

4) Continue work-up of 5 Scotian Prince cruises. Perform 5 more cruises in October.

d. Publications:

There were two peer-reviewed publication published in the last quarter. The complete citation is:

Voss, K., W. M. Balch, and K. A. Kilpatrick. Scattering and attenuation properties of Emiliania huxleyi cells and their detached coccoliths. Limnol. Oceanogr. 43(5) 870-876.

Esaias, W. E., M. R. Abbott, O. W. Brown, J. W. Campbell, K. L. Carder, D. K. Clark, R. L. Evans, F. E. Hoge, H. R. Gordon, W. M. Balch, R. Letelier, and P. Minnett. An overview of MODIS Capabilities for Ocean Science Observations. IEEE Transactions on Geoscience and Remote Sensing, 36, 1250--1265 (1998).

One manuscript is accepted and in press.

Balch, William M., David T. Drapeau, Terry L. Cucci, and Robert D. Vaillancourt, Katherine A. Kilpatrick, Jennifer J. Fritz. Optical Backscattering by Calcifying Algae. In press. J. Geophys. Res.

Two manuscripts were submitted for publication:

Graziano, L., W. Balch, D. Drapeau, B.Bowler, and S. Dunford. Organic and inorganic carbon production in the Gulf of Maine. To be submitted to Cont. Shelf Res.

Milliman, J., F. MacKenzie and W. Balch. Biologically-mediated dissolution above the lysocline- a major loss of oceanic calcium carbonate in the global ocean. Submitted to Deep Sea Research.